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OPTIMIZATION OF THE MANAGEMENT OF LARGE DAMS, TAKING INTO ACCOUNT CLIMATE CHANGE

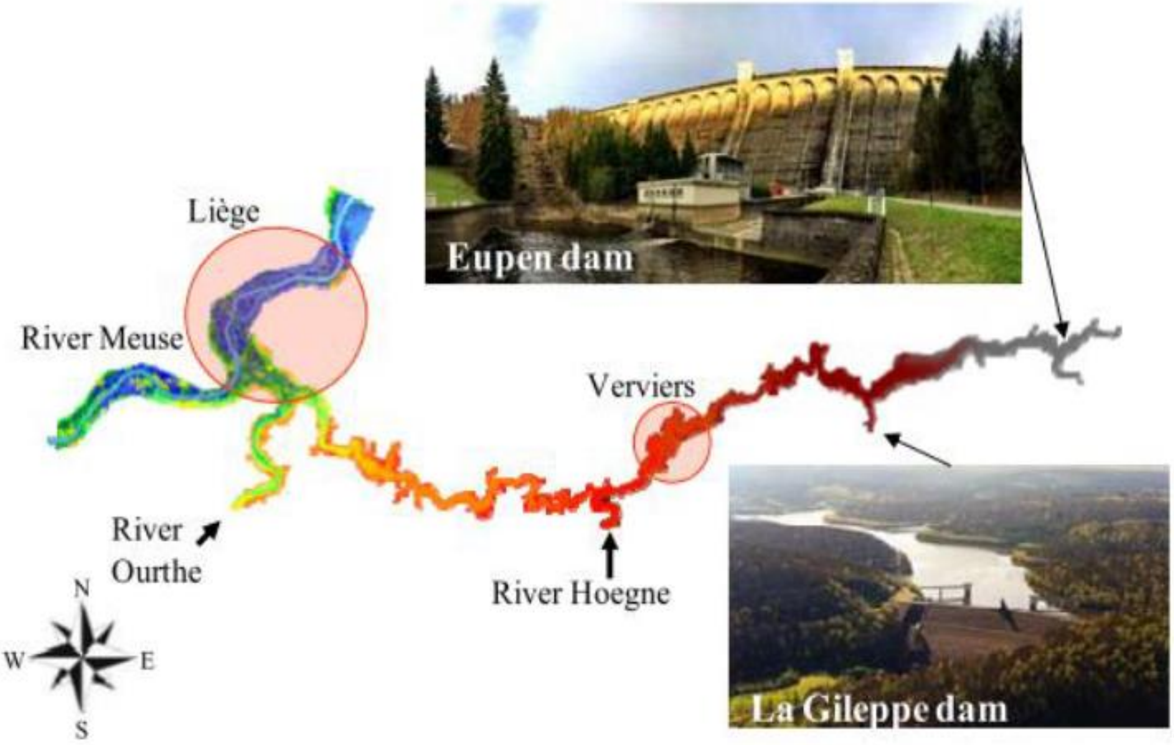

Figure 1-1 : Vallée de la Vesdre du barrage d'Eupen à la confluence avec l'Ourthe et la Meuse (Dewals, et al., 2011)

INTRODUCTION

The effects of climate change are as manifold and various than the variation of the oceans level, the migration of some kind of species,… The goal of this work is to study the effects of climate change on dams management.

This study is applied on two structures located in the Vesdre basin, in Belgium. From an integrated model including a climate model, a hydrological model of the Vesdre watershed, a hydraulic calculation model of this watercourse and a model of dams management, the Vesdre discharges and the lakes levels can be calculated. Thanks to climate data feeding the model, a study of the influence of some parameters of the dam management rule is done, after having defined some original performance indicators. These indicators represent the damages due to floods, the hydropower production, the support of low flows and the production of drinking water throughout the year. Afterwards, from two climate scenarios, a dry and a wet, the changes induced in the Vesdre valley and in the tanks water levels are determined at the time horizons 2020-2050 and 2070-2100. Then, the sensitivity analysis, performed in the period 1974-2004, is used to research adaptations in the management rule to mitigate the effects of climate change

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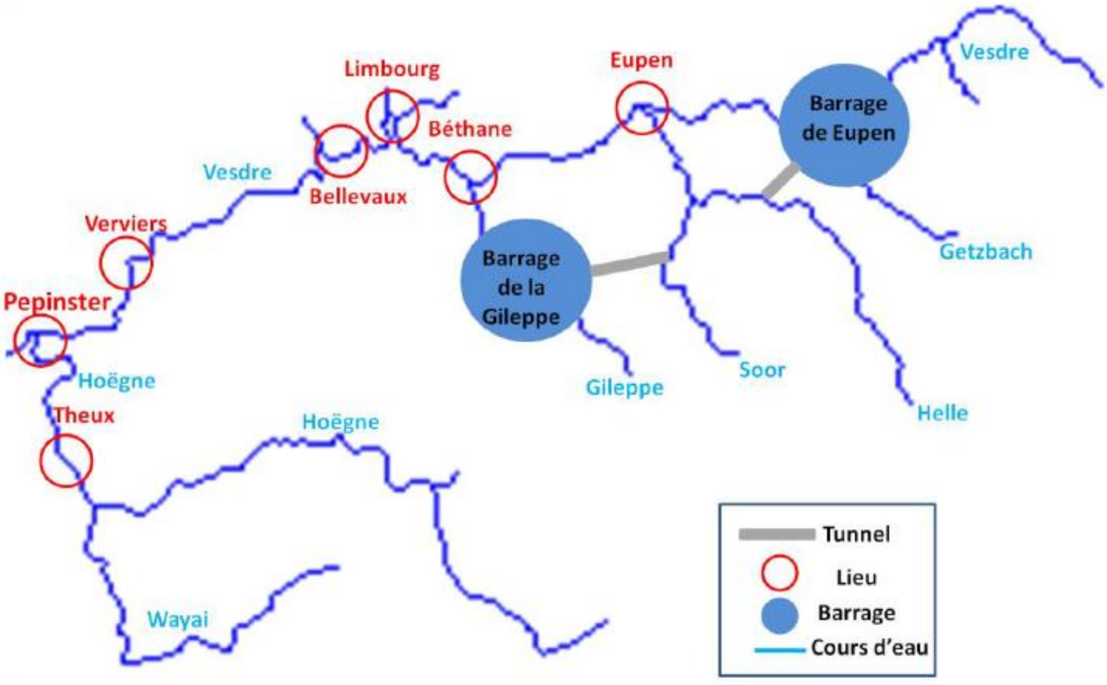


Figure 1-2 : Représentation schématique du réseau hydrologique de la Vesdre, de sa source jusqu'à sa confluence avec la Höegne

1-The multiple functions of a tank

During the construction of a water retention structure, the objectives which justified this construction can be many and varied. These different objectives are conventionally grouped into two main functions: reducing the impacts of downstream flooding and mitigating the consequences of a dry season on water volumes (Dewals, et al., 2011).

First, during flooding, the water runoff on the catchment area relating to the dam can be stored by the latter, provided that it has sufficient retention capacity called a sludge reserve. Thus, by temporarily preventing this volume of water from reaching the river downstream, the hydrograph relating to the watershed whose waters are retained by the dam can be subtracted from the total flood hydrograph, in the absence of the 'structure at any point downstream of the reservoir. This is flood clipping (Figure 2-1). Once the flood has passed, it is necessary to restore the sludge reserve by releasing water downstream, at a time when the danger of flooding has been eliminated. Obviously, this clipping of the flood will be all the more efficient as the watershed relative to the reservoir will represent a significant part of the entire watershed of the watercourse.

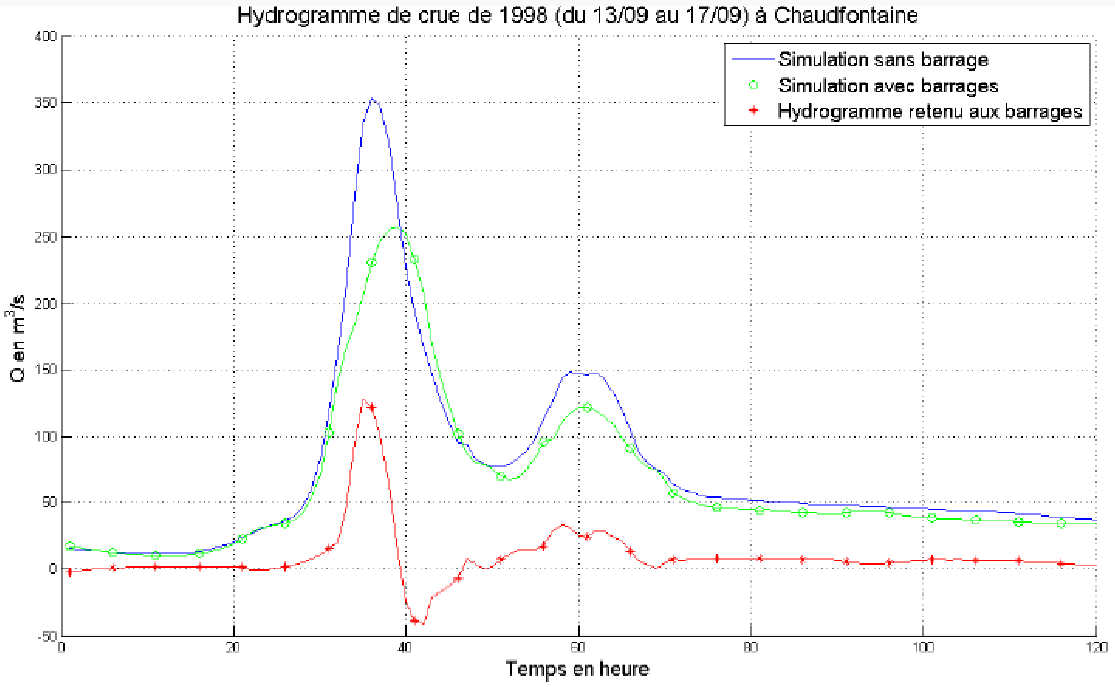


Figure 2-1 : Illustration de la fonction d'écrêtage de crue des barrages de la Vesdre sur l'hydrogramme de crue en aval des ouvrages de rétention

Indeed, the objective of maximum filling of the reserve, in anticipation of the dry season, is opposed to the objective of creating a sludge reserve. This conflict therefore results in a compromise which consists in ensuring a sufficient reserve for the storage of the flood that must be capped, by a possible preventive operation of emptying the backwater, without jeopardizing the objective of supplying water in dry periods.
Likewise, the low flow support function is opposed to the drinking water production function, following the water loss it causes.
Figure 2-2 clearly shows the main variables involved in optimizing the management of a reservoir.

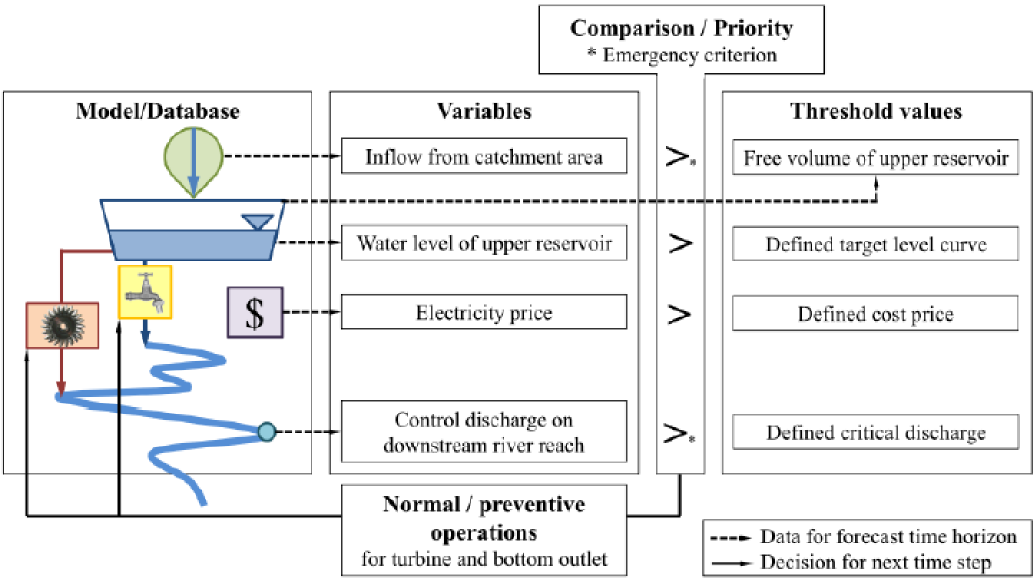

Comparison / Priority
* Emergency criterion
Model/Database
Variables
Threshold values
Inflow from catchment area
>*
Free volume of upper reservoir
Water level of upper reservoir
>
Defined target level curve
$
Electricity price
>
Defined cost price
Control discharge on downstream river reach
>*
Defined critical discharge
Normal / preventive operations
for turbine and bottom outlet
Data for forecast time horizon
Decision for next time step

Figure 2-2 : Variables et valeurs seuils influençant les opérations de gestion d’un ouvrage de retenue d’eau (Bieri, et al., 2013)

2-Methods of optimizing reservoir management

The future hydrological contributions of the watershed relating to the studied reservoirs are generally used to define an appropriate management of these reservoirs. By their nature, these inputs are random and can only be predicted with some precision in the very near future. Thus, optimal management of reservoirs is complex to define since it is based on a partial ignorance of the short-term input parameters and on a significant ignorance of these long-term parameters.

The study of the optimization of the production of hydroelectric power was approached in 1923 by Varlet, graphically by the Tense Wire method. In 1946, Massé provided proof of the effectiveness of the method proposed by Varlet through an economic and mathematical analysis of the marginal benefit derived from the production of hydroelectric power on a simple case. This Massé model will be generalized to several reservoirs and to several objectives thereafter, in a limited future (Morel-Seytoux, 1998). A review of the state of the art concerning the optimal management of reservoirs was carried out by J. W. Labadie (2004). The problem arises from an objective function incorporating criteria that may be economic, environmental, ecological or social. Besides this objective function, various constraints are defined relating to the extreme levels of the lakes, the low flow rates downstream of the reservoirs, etc. When possible, a definition of the objective function in terms of costs simplifies the resolution. of the problem by finding the minimum of this function (Watkins, et al., 2006). Various cost functions were developed for this purpose (Jordan, 2007). There is a large number of methods allowing the resolution of the problem posed: implicit stochastic optimization, linear and nonlinear programming models, stochastic dynamics,... These various models are also presented in the article by JW Labadie (2004), but will not be not used for this job. The concern is that management objectives cannot always be quantified in monetary units. Consider the environmental consequences of low flow rates or the social consequences of a shortage of drinking water supply. In this case, the definition of an objective function to be minimized can be replaced by a multicriteria analysis

3-Local sensitivity analysis

The presentation of local sensitivity analysis, as used in this work, is mainly based on the thesis of S. Wildemeersch (2012). It is used in the relaxation phase of the parameters in order to determine their respective influences on the performance indicators. Local sensitivity analysis involves studying a system around a limited number of parameters studied independently. Theoretically, this method is only valid in linear models, but practice has shown it to be acceptable when the model is not "extremely non-linear" (Hill, et al., 2007). The advantage of this method is that it considerably reduces the number of simulations to be carried out. However, the order of magnitude of a simulation being several days, this simplification is essential in the context of this work

After having chosen a certain number of parameters bi to vary and the performance indicators yj representative of the tank objectives, the sensitivity matrix J can be created by a number of simulations corresponding to the number of parameters:

$$J = \begin{pmatrix} \left.\frac{\partial y_1}{\partial b_1}\right|_b & \cdots & \left.\frac{\partial y_1}{\partial b_{npar}}\right|_b \\ \vdots & \ddots & \vdots \\ \left.\frac{\partial y_{nind}}{\partial b_1}\right|_b & \cdots & \left.\frac{\partial y_{nind}}{\partial b_{npar}}\right|_b \end{pmatrix}$$

With $npar$ the number of parameters and $nind$ the number of indicators.

Once the matrix J is completed, the influences of the parameters on the indicators are analyzed by the dss for *dimensionless scaled sensitivities* and by the css for composite scaled sensitivities. The elements $dssij$ assess the importance of the variations of indicator i as a function of parameter j, by dimensionless formatting. The elements $cssij$ are a measure of the sensitivity of all the indicators to a parameter j and therefore make it possible to choose the most influential parameters to keep for optimization.

$$dss_{ij} = \left.\frac{\partial y_i}{\partial b_j}\right|_b \times |b_j| \times \left|\frac{1}{y_i}\right| \quad \text{(2-2)}$$

$$css_j = \left(\frac{\left(\sum_{i=1}^{nind} \left.(dss_{ij})^2\right|_b\right)}{nind}\right)^{1/2} \quad \text{(2-3)}$$

4-Integrated model of the Vesdre basin

Optimizing the management of the Vesdre dams, with a view to reducing the damage caused by floods, guaranteeing a continuous supply of water throughout the year, producing a maximum quantity of hydroelectric energy and supporting the low flows, taking into account climate change, requires a number of numerical models listed below (Pohl, et al., 2006).

- A climate model for determining precipitation and temperature;
- A hydrological model for converting climatic data into inflow flows over the entire watershed of the watercourse;
- A reservoir management model (developed in the next chapter);
- A hydraulic model of the watercourse with, as inputs, the inflow rates of the hydrological model;
- Possibly, a flood risk calculation model allows a more precise quantification of the objective of limiting flood damage.

All the climatic, hydrological, hydraulic, reservoir management and flood damage calculation models are grouped into an integrated model of the Vesdre basin, developed within the framework of the AMICE project (Detrembleur, et al., 2012). However, analyzes of climate change and the sensitivity of the parameters of the management law of the Eupen and Gileppe dams do not require the full use of the integrated model of the Vesdre basin developed. Indeed, based on the results provided by the integrated model of the AMICE project, the use of a one-dimensional hydraulic model, fed by the climatic and hydrological models, is sufficient to update the results of the complete model. It goes without saying that the gain in terms of computation time is substantial and justifies this approach. The different models constituting the integrated model of the Vesdre basin are first presented below. Then, the process of updating the data necessary for studies of the influences of the parameters of the management law and analyzes of the effects of climate change is presented.

3-1 Climate model

The presentation of the climate model is based on a report from the AMICE project (Drogue, et al., 2010). This model uses the Delta change approach, considered robust and transparent, to account for climate change (te

Linde, et al., 2010; Fortin, et al., 2007). This method consists in projecting the precipitation and temperatures, measured in recent years, to the time horizons 2020-2050 and 2070-2100, from seasonal trends influenced by the greenhouse gas emission scenarios selected, among the set of scenarios developed by the IPCC (IPCC, 2007) (Figure 3-1). The use of regional climate models (RCM) allows to refine the results obtained by global climate models (GCM).

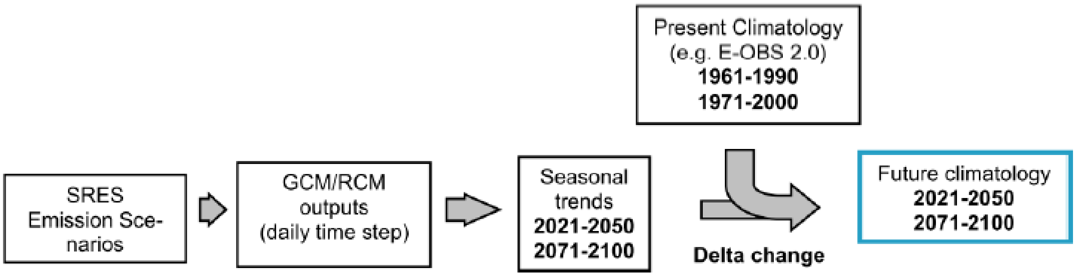


Figure 3-1 : Génération de scénarios climatiques à partir de la méthode du changement delta (Drogue, et al., 2010)

All the scenarios developed by the IPCC being equiprobable at present, two extreme scenarios, among the multitude of scenarios simulated by the IPCC, one dry and one wet, were chosen within the framework of the AMICE project.

On the basis of these scenarios, projections concerning precipitation and temperatures, in the Walloon part of the Meuse watershed, were made for the two time horizons studied. In Figure 3-2, the temperature is increasing in all seasons and regardless of the greenhouse gas emission scenario chosen. Then, precipitation is reduced in summer in both scenarios and increased in winter in the wet scenario.

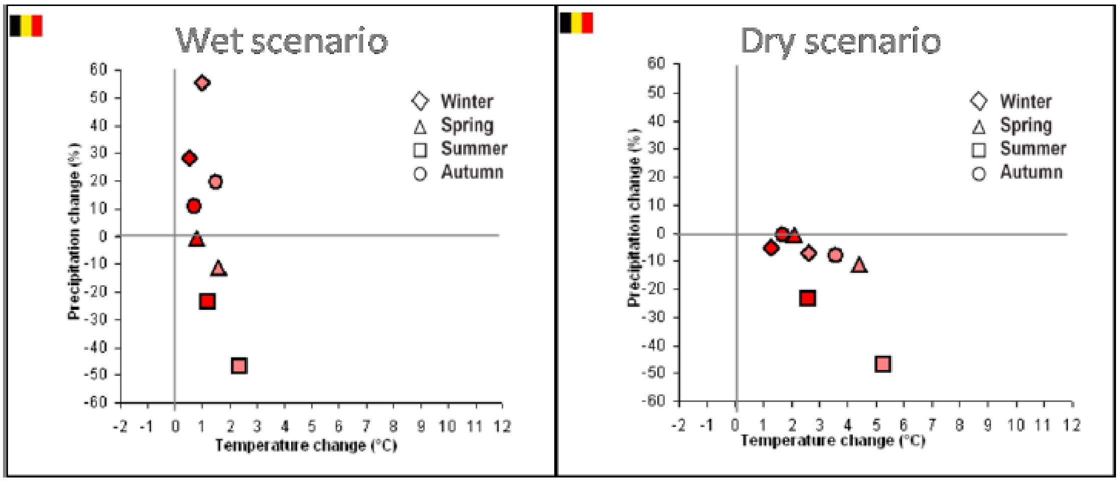
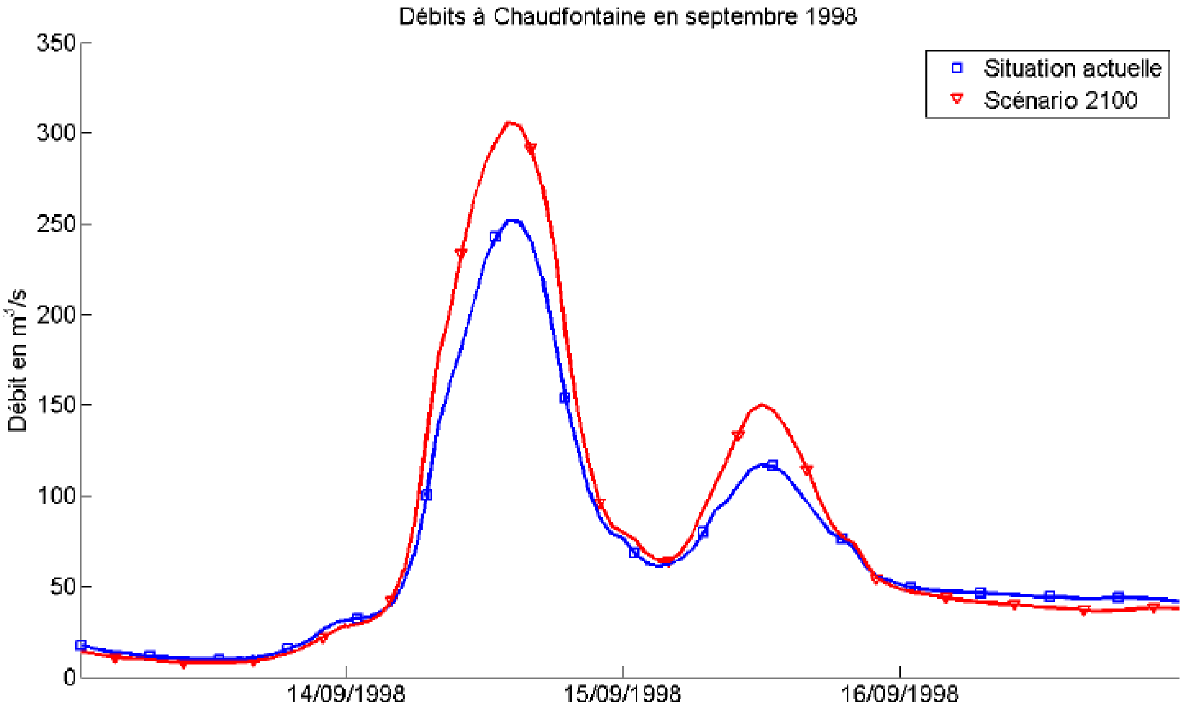


Figure 3-2 : Tendances saisonnières des précipitations et températures, selon le scénario utilisé, et pour les horizons temporels 2020-2050 (foncé) et 2070-2100 (clair) (Drogue, et al., 2010)

To illustrate the principle of Delta change, Figure 3-3 compares the flows at Chaudfontaine, during the major flood of September 1998, with the humid climate scenario for the 2070-2100 horizon, created by disruption of current climate data.



igure 3-3 : Principe du changement Delta illustré sur les débits à Chaudfontaine en septembre 1998

3-2 : Description and modeling of the current management procedure

It is important to stress that the current management of dams, in practice, is not automatic, but results from decisions made by one or more people, however based on the procedure described in the handling note. The simulation created therefore inevitably deviates from the actual management

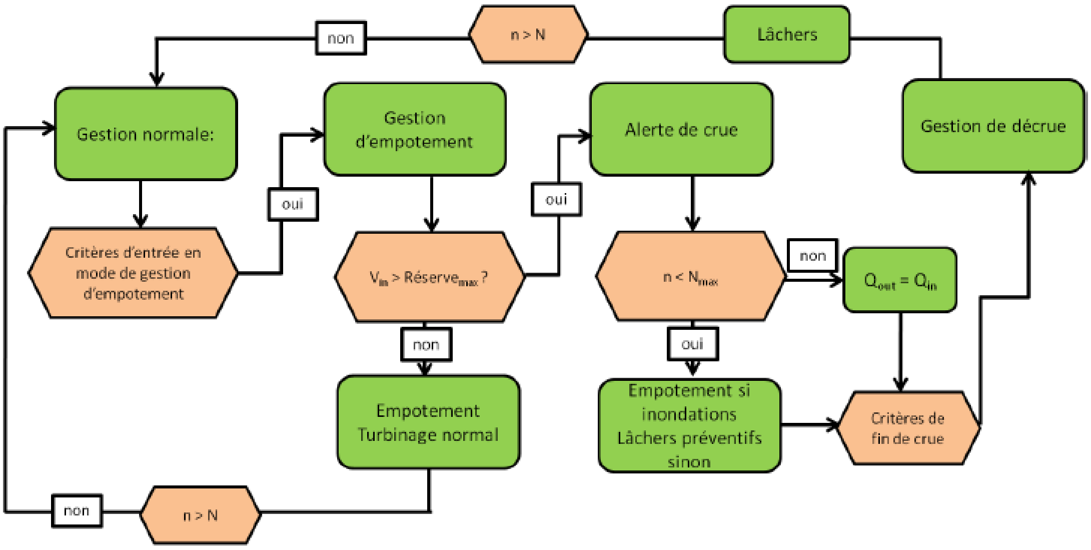


Figure 4-1 : Résumé de la modélisation initiale de la loi de gestion des barrages de la Vesdre.

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